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Study of Emission Reduction: Benefits of Urban Rail Transit

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Abstract

As many cities in China have been planning, establishing and operating urban rail transit (URT), it is necessary to study URT's impacts on emission reduction. In this paper, the environmental benefit strategy was addressed through the real operating data and travel behavior data of Beijing's URT, using the skeleton planning method to estimate HC, CO, NO_x emission reductions. Moreover, the study calculates the direct economic benefits of URT in terms of fuel consumption savings and air pollution control cost savings. The results show that URT operation can not only encourage the use of URT, but also reduces mobile source emissions substantially, thus creating substantial environmental benefits. Our results show that the URT of Beijing could reduce 1036.733 ton of HC, 85.827 ton of CO, 326.295 ton of NO_x, which leads to over 8.56 billion Yuan savings every year. More specifically, the findings of this paper have insightful implications to planning, construction, operation and assessment of URT.

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Keywords: Urban rail transit; Environmental benefit; Mobile source emission; Economic value; Skeleton planning method

1. Introduction

With the concept of "low-carbon, green transportation and a growing number of cities operating URT, a large number of scholars began to study the rail transit environment. Liu et al. (2010) built a dynamic optimization model for urban traffic environmental system based on passenger trip generating which can be used to simulate the developing characteristics of urban passenger traffic system. Luo & Liu (2006) clarified the superiorities of URT in transportation system on the aspects of resource, energy utilization efficiency, and pollution reduction based on the basic theory of eco-city and pointed out that a rail transit could also lead the optimization of urban

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construction. Chen (2012) explained that URT system is an important component of the urban ecological environment and one of our basic duties is to study and design the scientific and rational green transportation system. Topalovic et al. (2012) and Poudenx (2008) studied the environmental impact of rail transit operators and carbon emissions, and pointed out that the development of public way to travel including URT with reducing private car travel is conducive to the energy saving and environmental improvements of city. Li, Hu, and Shao (2012) used scenario analysis method to clarify the effects of accelerated development of Shanghai's urban rail transit on greenhouse gas emission (GHG) reductions based on analysis of the annual changes of traffic modes and GHG emissions. Gan, Sun, and Lu (2010) used the skeleton planning method to estimate the environmental benefits including emission reduction and the direct economic benefits of the P+R strategy through a case of the first P+R user travel behavioral data. As can be seen from the above, they are public transport effect on the environment as well as the environmental benefits of the P + R strategy. There are few studies or a case study on environment benefit of URT.

The environmental benefits of rail transportation were set as a goal in the paper. We analyze the influencing factors of the environmental benefits of URT at first, and then made empirical studies of the environmental benefits which used the skeleton planning method (SPM) and the actual data of Beijing URT to calculate emission reduction of HC, CO and NOx. At last, we evaluated the direct economic value of saving of the fuel consumption costs and air pollution control cost.

2. Environmental benefits of rail traffic impact factors

URT is a low-carbon, green transportation mode. The construction and operation of URT is to encourage people to travel by URT with reducing vehicle travel which reduce mobile source emission. The factors have the main impact on the environmental benefits of URT including the passengers of URT, the type of transportation mode used by the passengers in the past and average distance that the passenger take the URT to travel.

Passenger volume which can be obtained from the actual operational data is related to URT fares and its reachability. The passengers of URT are greater that explained the more passengers transferred from ground transportation to URT. The proportion of URT passengers from the bus or car determined the emission reduction of mobile. The per capita emissions of bus are far less than the per capita emissions of car. When all URT passengers come from the bus, mobile source emission reduction caused by URT operation will reach the minimum. If more URT passengers come from the car, the environmental benefits of URT will be more significant. Mobile source emissions are directly proportional to the traveling distance which demonstrates that the longer the distance, the more is mobile source emissions. So the travelers take the longer average trip distance of URT that mobile source emission reduction will be more and environmental benefits will be more significant.

The environmental benefits estimating flowchart of URT is given in Figure 1 which illustrated the estimating ideas of the environmental benefits of URT.

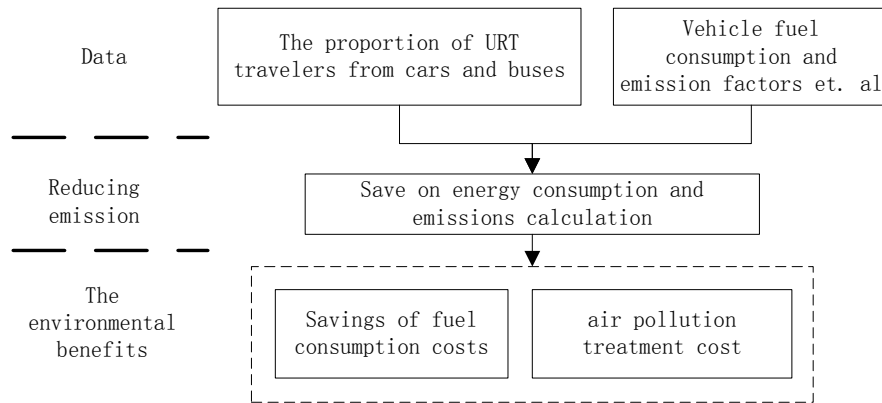


Fig.1 Environmental benefits of URT estimating flowchart

3. Calculation of emission reduction by the URT operation

Song et al. (2011) made the study of city-specific emission factors and the composite emission factor for Beijing, Shanghai Tianjin, and Chengdu which are demonstrated in the Table 1. The composite emission factor was used in this paper that the bus uses the data of bus and the car uses data of taxi.

The environmental benefits of Beijing metro have a certain degree of representativeness because of the network operation. So Beijing metro was taken as an example to analysis. Beijing transportation annual report showed that the annual passengers of Beijing metro was up to the 1.85 billion people and the average travel distance was 16.357Km in the year of 2011.

Table 1 City-specific emission factors and the composite emission factor for Beijing, Shanghai, Tianjin and Chengdu

Type of vehicle	emission factors /($\text{g} \cdot \text{km}^{-1}$)					
	car			bus		
	CO	HC	NO _x	CO	HC	NO _x
Beijing	19.68	2.18	0.76	45.72	3.21	4.76
Shanghai	27.55	1.94	2.11	28.28	2.41	9.89
Tianjin	41.44	3.27	1.44	17.78	2.35	17.92
Chengdu	35.83	0.61	0.62	10.33	0.26	1.38
composite factor	25.89	1.89	0.91	27.42	2.27	8.63

Due to the large volume of bus, the per capita emissions of bus are far less than car's. So when the proportion of URT passengers coming from the bus is equal to 1, mobile source emission reduction caused by URT operation will reach the minimum. If the minimum emissions are considerable, the total mobile source emission reduction that the proportion of URT passengers coming from the car for any value will be greater than mobile source emission reduction that the passengers only from buses. This article assumes that the proportion of URT passengers from cars is 0 and the proportion of bus is 1 to estimate environmental benefits of URT.

3.1. Variable Symbol Description

The variables and the corresponding symbols which are used to compute the environmental benefits are shown in table 2.

Table 2 Variables and the corresponding symbols

Symbol	Variable name	Symbol	Variable name
fc	The proportion of URT passenger from car	Ebco	CO emission factor of bus
fb	The proportion of URT passenger from bus	Ebhc	HC emission factor of bus
P	Total volume of URT	Ebno	NO emission factor of bus
Pc	The passengers from car	Rcco	CO emissions reduction by the car
Pb	The passengers from bus	Rchc	HC emissions reduction by the car
Sc	The total distance by car	Rcno	NO emissions reduction by the car
Sb	The total distance by bus	Rbco	CO emissions reduction by the bus
Rc	Annual reduction of car mileage	Rbhc	HC emissions reduction by the bus
Rb	Annual reduction of bus mileage	Rbno	NO emissions reduction by the bus
Sua	Average traveling distance by URT	Rco	Total reduction of CO
Ecco	CO emission factor of car	Rhc	Total reduction of HC
Echc	HC emission factor of car	Rno	Total reduction of NO
Ecno	NO emission factor of car		

3.2. The calculation of emission reduction

Step 1: computing the number of passengers transferred from cars and bus

The passengers from car equals to the total travelers by URT multiplied by the proportion of URT passenger from car.

$$Pc = P \times fc = 18.5 \times 10^8 \times 0 = 0 \text{ (trips)} \quad (1)$$

The passengers from bus equals to the total travelers by URT multiplied by the proportion of URT passenger from bus.

$$Pb = P \times fb = 18.5 \times 10^8 \times 1 = 18.5 \times 10^8 \text{ (trips)} \quad (2)$$

Step 2: computing total travel distance by cars and buses

The total distance by car equals to the number of passengers from car multiplied by average traveling distance by URT.

$$Sc = Pc \times Sua = 0 \times 16.35 = 0 \text{ (Km)} \quad (3)$$

The total distance by bus equals to the number of passengers from bus multiplied by average traveling distance by URT.

$$Sb = Pb \times Sua = 18.5 \times 10^8 \times 16.35 = 3.025 \times 10^{10} (Km) \quad (4)$$

Step 3: computing annual reduction of car mileage and bus mileage

Annual reduction of car mileage equals to the total distance by car divided by average number of passenger by car. We assume that there are 3 people in the car.

$$Rc = Sc / 3 = 0 / 3 = 0 \times 10^8 (Km) \quad (5)$$

Annual reduction of bus mileage equals to the total distance by bus divided by average number of passenger by bus. We assume that there are 80 people in the bus.

$$Rb = Sb / 80 = 3.025 \times 10^{10} / 80 = 3.781 \times 10^8 = 3.781 \times 10^8 (Km) \quad (6)$$

Step 4: computing emission reduction of CO(Rcco), HC(Rchc) and NO(Rcno) of car

CO emissions reduction by the car equals to CO emission factor of car multiplied by annual reduction of car mileage.

$$Rcco = Ecco \times Rc = 1.89 \times 0 = 0 (ton) \quad (7)$$

HC emissions reduction by the car equals to HC emission factor of car multiplied by annual reduction of car mileage.

$$Rchc = Ehc \times Rc = 25.89 \times 0 = 0 (ton) \quad (8)$$

NO emissions reduction by the car equals to NO emission factor of car multiplied by annual reduction of car mileage.

$$Rcno = Ecno \times Rc = 0.91 \times 0 = 0 (ton) \quad (9)$$

Step 5: computing emission reduction of HC(Rbhc), CO(Rbco) and NO(Rbno) of bus

CO emissions reduction by the bus equals to CO emission factor of bus multiplied by annual reduction of bus mileage.

$$Rbco = Ebco \times Rb = 2.27 \times 3.781 \times 10^8 = 85.827 \times 10^4 (ton) \quad (10)$$

HC emissions reduction by the bus equals to HC emission factor of bus multiplied by annual reduction of bus mileage.

$$Rbhc = Ebhc \times Rb = 27.42 \times 3.781 \times 10^8 = 1036.733 \times 10^4 (ton) \quad (11)$$

NO emissions reduction by the bus equals to NO emission factor of bus multiplied by annual reduction of bus mileage.

$$Rbno = Ebno \times Rb = 8.63 \times 3.781 \times 10^8 = 326.295 \times 10^4 (ton) \quad (12)$$

Step 6: computing the total emission reduction of HC(Rhc), CO(Rco) and NO(Rno)

Total reduction of CO equals to CO emission factor of car plus CO emission factor of bus.

$$Rco = Rcco + Rbco = 0 + 85.827 = 85.827 \times 10^4 (ton) \quad (13)$$

Total reduction of HC equals to HC emission factor of car plus HC emission factor of bus.

$$R_{hc} = R_{chc} + R_{bhc} = 0 + 1036.733 = 1036.733 \times 10^4 (\text{ton}) \quad (14)$$

Total reduction of NO is the sum up of NO emission factor of car and NO emission factor of bus.

$$R_{no} = R_{cno} + R_{bno} = 0 + 326.295 = 326.295 \times 10^4 (\text{ton}) \quad (15)$$

4. Economic value caused by emission reduction

Directed economic value of the environmental benefits of this study only contains the saving of fuel consumption costs because that URT operation reduce vehicle mileage and air pollution control costs for mobile source emission reduction. The economic value of social benefits caused by the improvement in the quality of the environment is not considered in the study for that it is subjected to many uncertainties factors.

Car fuel consumption is influenced by many complex factors such as car's weight, road conditions, auto emission, speed, and engine temperature. The fuel consumption of the car or bus can use the weighted average value of different vehicle types of different cities. Fuel consumption takes the weighted average value of the 93 # and 97 # gasoline. In this paper, the average value of vehicle fuel consumption was used to analyze the savings of fuel consumption caused by URT operation which reduced vehicle mileage and fuel consumption. Fuel consumption of car is used 10 liters/100 km. and bus is used 30 liters/100 km. The price of oil is calculated at 8.06 Yuan/L which is actual oil price of 93 # gasoline in Beijing

4.1. Variable Symbol Description

The variables and the corresponding symbols which are used to compute the economic benefits are shown in table 3.

Table 3 Variables and the corresponding symbols

Symbol	Variable name	Symbol	Variable name
Ghc	Fuel consumption of car (L/100km)	M	Economic value
Ghb	Fuel consumption of bus (L/100km)	M1	The total cost of fuel consumption savings
Gc	Car fuel consumption savings	R	The total emissions reduction
Gb	Bus fuel consumption savings	Me	The unit air control costs (Yuan/ton)
Ms	The unit price of gasoline (Yuan/L)	M2	Air control costs
Mgc	The cost of car fuel consumption savings	Mgb	The cost of bus fuel consumption savings

4.2. the economic value caused by emission reduction

This section is based on the results of section 2.2.

Step 1: computing the running mileage reduction of cars and buses caused by URT

Annual reduction in car mileage equals to the total distance by car divided by average number of passengers by car. We assume that there are 3 people in the car.

$$R_c = S_c / 3 = 0 (\text{Km}) \quad (16)$$

Annual reduction in bus mileage equals to the total distance by bus divided by average number of passengers by bus. We assume that there are 80 people in the bus.

$$Rb = Sb / 80 = 3.025 \times 10^{10} / 80 = 3.781 \times 10^8 = 378.1 \times 10^6 (Km) \quad (17)$$

Step 2: computing fuel consumption savings due to the reduction in mileage

Car fuel consumption savings equals to annual reduction in car mileage divided by 100 then multiplied by fuel consumption of car.

$$Gc = Rc / 100 \times Ghc = 0 / 100 \times 10 = 0(L) \quad (18)$$

Bus fuel consumption savings equals to annual reduction in bus mileage divided by 100 then multiplied by fuel consumption of bus.

$$Gb = Rb / 100 \times Ghb = 3.781 \times 10^8 / 100 \times 30 = 1.134 \times 10^8 = 1.134 \times 10^8 (L) \quad (19)$$

Step 3: computing the total cost of fuel consumption savings

The cost of car fuel consumption savings equals to car fuel consumption savings multiplied by the unit price of gasoline.

$$Mgc = Gc \times Ms = Gc \times 8.06 = 0(Yuan) \quad (20)$$

The cost of bus fuel consumption savings equals to bus fuel consumption savings multiplied by the unit price of gasoline.

$$Mgb = Gb \times Ms = Gb \times 8.06 = 1.134 \times 10^8 \times 8.06 = 9.142 \times 10^8 (Yuan) \quad (21)$$

Step 4: computing the total cost of fuel consumption savings

The total cost of fuel consumption savings is the sum up of the cost of car fuel consumption savings and the cost of bus fuel consumption savings.

$$M1 = Mgc + Mgb = 0 + 9.142 = 9.142 \times 10^8 (Yuan) \quad (22)$$

4.3. Savings of air pollution control costing

Step 1: computing the total emissions reduction

The total emissions reduction equals to total reduction of CO is the sum up of total reduction of HC and total reduction of NO.

$$R = Rco + Rhc + Rno = 1036.733 + 85.827 + 326.295 = 1448.855 \times 10^4 (ton) \quad (23)$$

Step 2: computing air control costs

Economic value equals to the unit air control costs (Yuan/ton) multiplied by the total emissions reduction.

$$M2 = Me \times R = 500 \times 1448.855 = 72.443 \times 10^8 (Yuan) \quad (24)$$

4.4. Economic value

From the above analysis, the economic value calculation of emission reductions is the sum up of the total cost of fuel consumption savings and air control costs.

$$M = M1 + M2 = 9.142 + 72.443 = 81.585 \times 10^8 \text{ (Yuan)} \quad (25)$$

5. Conclusion

The environmental benefits of URT are obvious. The estimating ideas and method of the environmental benefits of URT was illustrated this paper. In this paper, the real operating data and travel behavioral data of Beijing URT were used to address the environmental benefit strategy and using the skeleton planning method to estimate HC, CO, NOX emission reductions. Moreover, the study calculates the direct economic benefits of URT in terms of fuel consumption savings and air pollution control cost savings. The URT operation of Beijing reduced 1036.733 tons of HC, 85.827 tons of CO, 326.295 tons of NOx, which leads to over 8.56 billion Yuan every year. This article assumes that all the Beijing metro passengers come from the bus, if the proportion of URT passengers from the car increases, it will generate higher economic value. The construction and operation of URT can not only encourage the use of URT, but also reduce mobile source emissions substantially, thus creating substantial environmental benefits. More specifically, the findings of this paper have insightful implications to planning, construction, operation and assessment of URT.

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References

- Liu H., Guo H. C., Yu Y. J., Wang Z., Liu T. (2010) Study on Optimization of Urban Passenger Traffic Environmental System Based on Trip. *Acta Scientiarum Naturalium Universitatis Pekinensis*; 46(1): 121-128.
- Luo X., Liu M. (2006). Effect of Urban Rail Transit on Eco- city Construction. *Urban Environment & Urban Ecology*; 19(2): 30-32.
- Chen Z. (2012). The Impact of Urban Transit on Ecological Environment. *China Railway Science*. 2(3): 126-132.
- Topalovic P., Carter J., Topalovic M., Krantzberg G. (2012) Light Rail Transit in Hamilton: Health, Environmental and Economic Impact Analysis. *Social Indicators Research*; 2012; 108(2): 329-350
- Poudenx P. (2008). The effect of transportation policies on energy consumption and greenhouse gas emission from urban passenger transportation. *Transportation Research Part A: Policy and Practice*; 2008; 42(6):901-909.
- Li L. F., Hu J., Shao D. (2012). Effects of accelerated development of urban rail transit in Shanghai before the World Expo on greenhouse gas emission reduction. *China Environmental Science*. 2012; 32(6): 1141-1147.
- Gan H. C., Sun L., Lu H. (2010). Empirical Study of Emission Reduction: Benefits of Park and Ride Strategy. *Systems Engineering*; 2010; 28(6): 101-105.
- Song N., Zhang K. S., Li Y., Chen L. (2011). Vehicle emissions comparisons among different cities and a simple emission estimation approach. *Acta Scientiae Circumstantiae*; 2011; 31(12): 2774-2784.
- Beijing transportation research center. *Beijing Transportation Annual Report (2011)*. Beijing. 2011,8.